AI-supported low CO_2 circular design

19th April

PhD Candidate: Peng Lee

Daily Supervisor and Co-promoter: Henriette Bier

Promoter: Paul Vermeulen

Contents

Research Background

Energy and Process-related CO_2 Emission

39%

28% Operation

11% **Construction**

Resulted from manufacturing building materials and products such as steel, cement and glass.

Material Extraction

50%

⬇

35% Waste

(IEA, 2019; EU Commission, 2019)

Research Background

Energy and Process-related CO_2 Emission

39%

Reuse

28% 11%

Operation

Construction

Resulted from manufacturing building materials and products such as steel, cement and glass.

Material Extraction

50%

↓

35%

Waste

(Inter De Wolf et al., 2022)

Research Background

Embodied Energy

Resource input

Reuse

11%

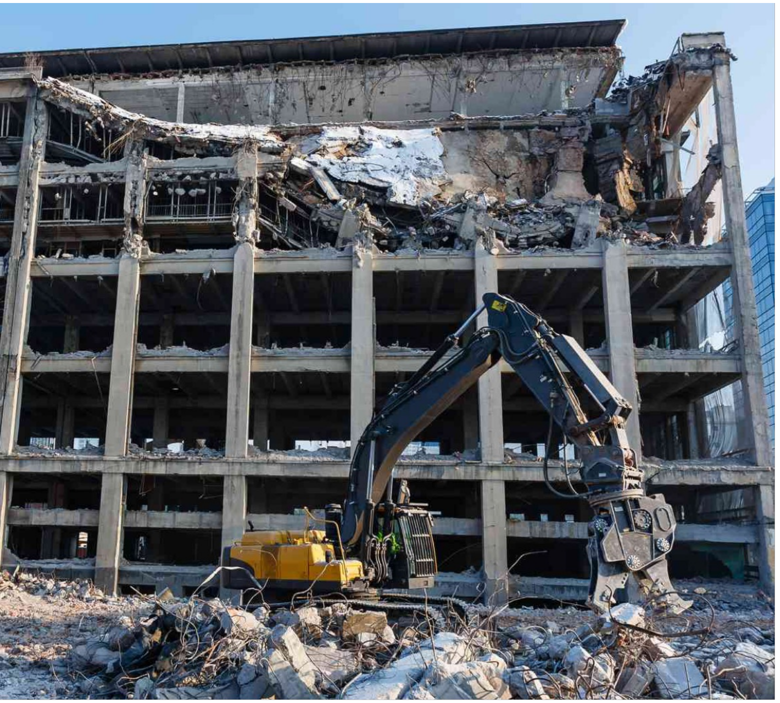
Construction

Resulted from manufacturing building materials and products such as steel, cement and glass.

Embodied Carbon (EC)

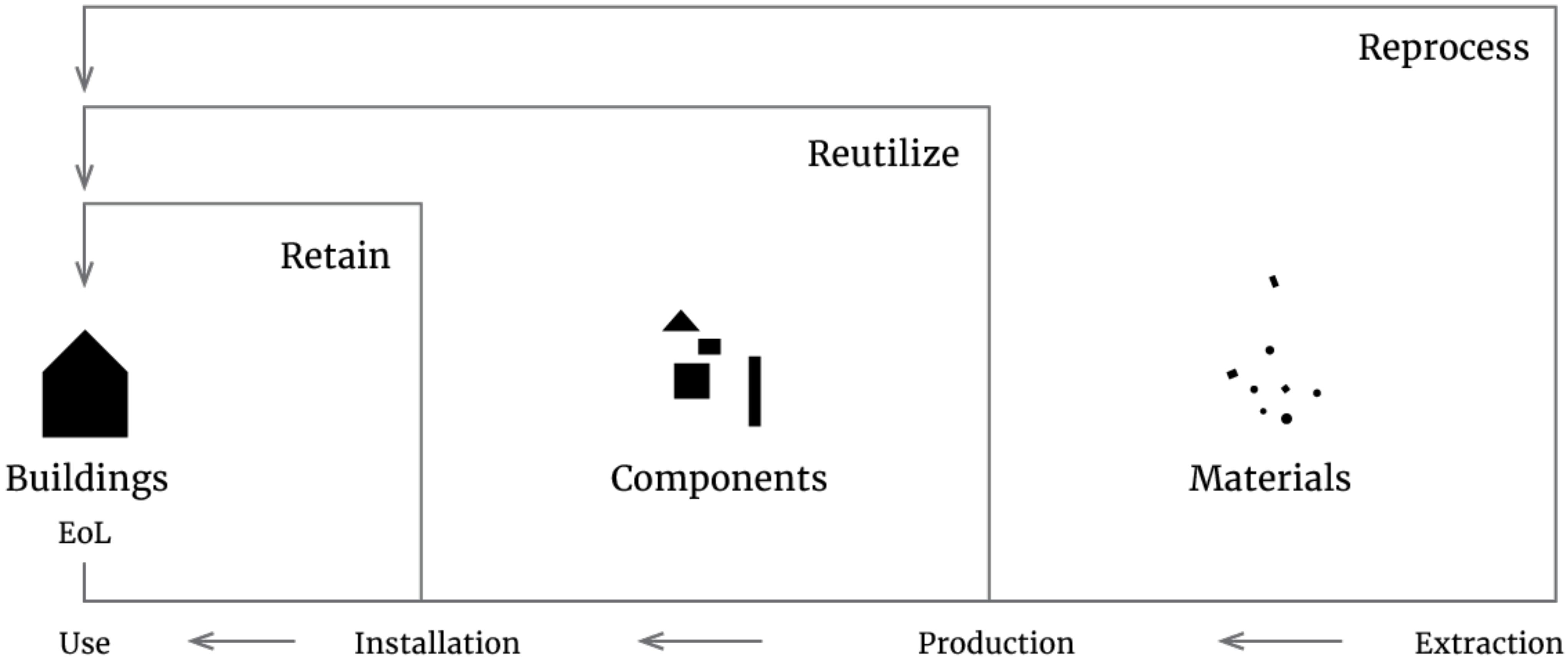
(Röck et al., 2020)

Research Background



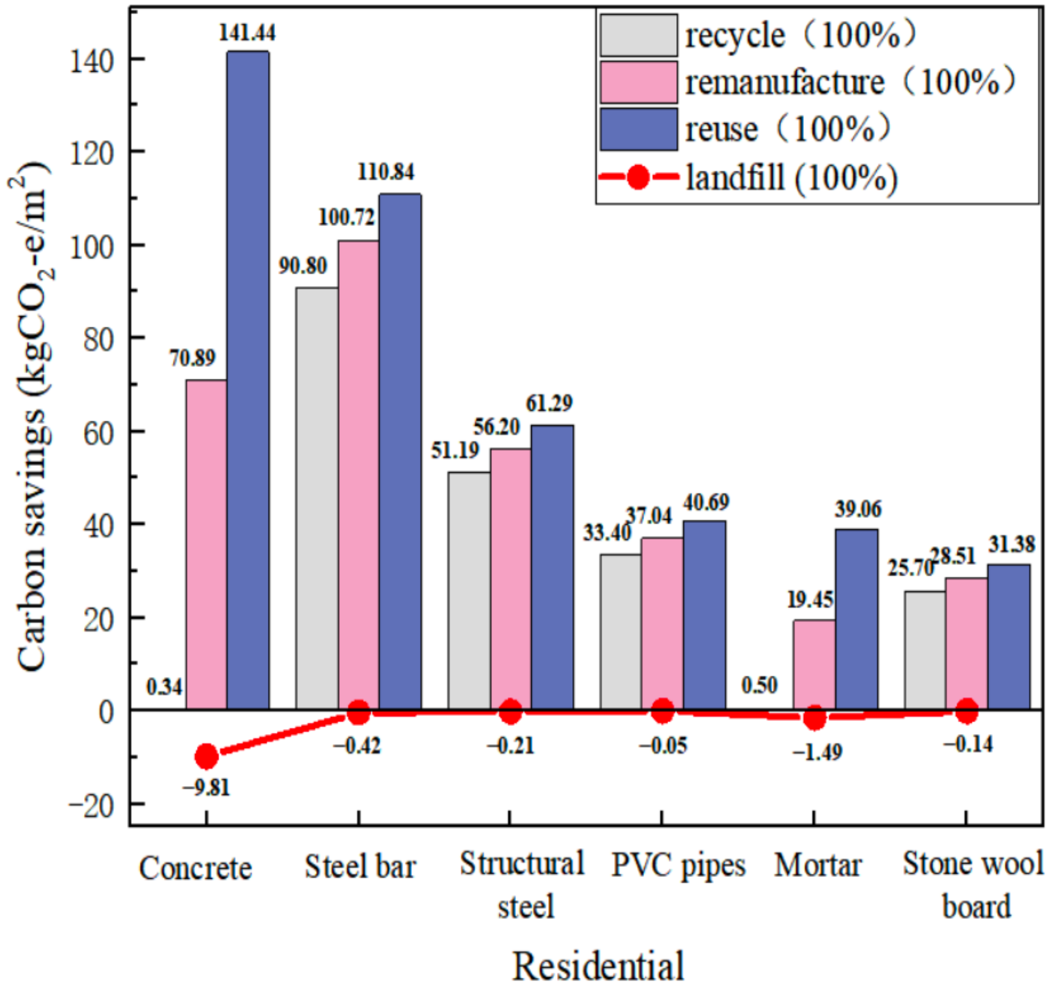
(Röck et al., 2020)

Type of Reuse



(Adapted from Stricker et al. 2022)

State-of-the-art: Reuse to Decarbonize



- Reutilize (direct)
- Reutilize (refurbish)
- Reprocess

- Various decarbonization effect

(Lei et al., 2023)

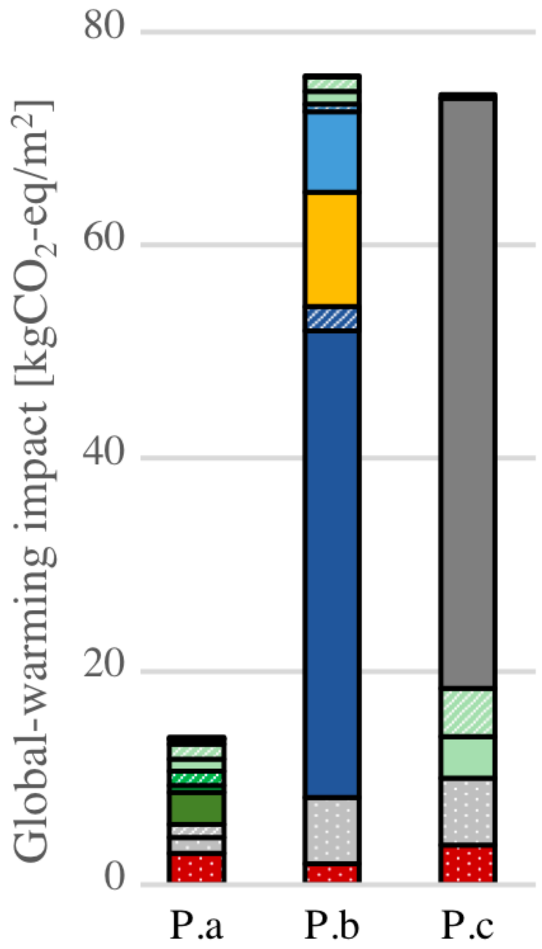
State-of-the-art: Reutilize to Decarbonize

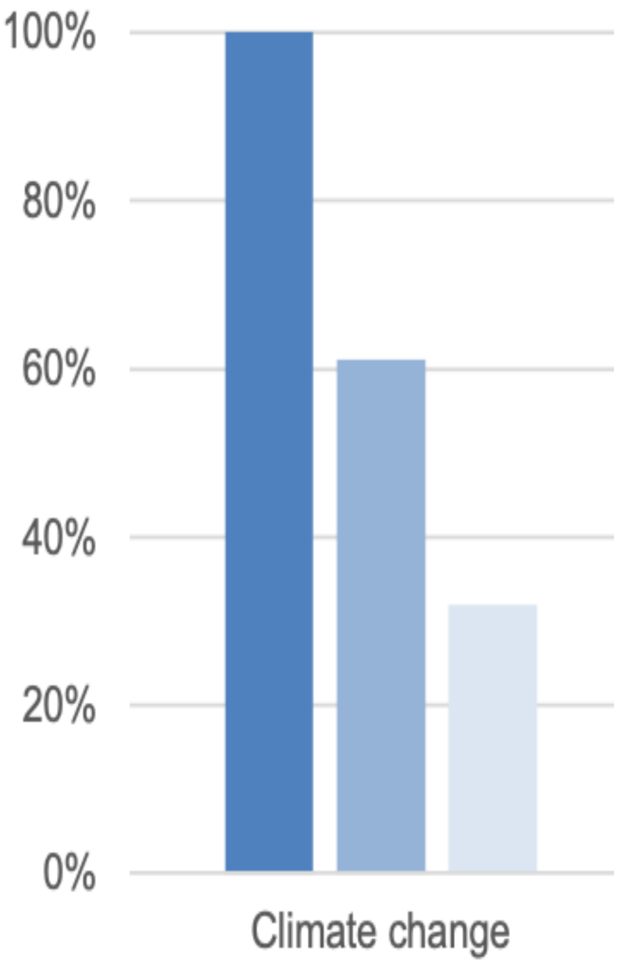
Case-study code	Compared design alternative, as described in the record(s)	Environmental-impact difference [unit]	Source
C20	New cast-in-place concrete building	– **60** [% CO2]; – **40** [% MJ]	Roth and Eklund (2000)
C38	Traditional dike construction	– **30** [% m^2]; – **26** to – **28** [% l]	Mettke (2010)
C46	Non-reuse alternative	– **97** [% CO_2]	Mettke (2017)
C56	New hollow-core slabs (vs 71% reuse)*	– **53** [% CO_2eq]; – **56** [% $€_1$]	Naber (2012)
C57	New hollow-core slabs (vs 69% reuse)*	– **56** [% CO_2eq]; – **50** [% $€_1$]	Naber (2012)
C58	Recycled-concrete house	– **90** [% CO_2eq]; – **75** [% $€_1$]	Glias (2013)
C67	New concrete building	– **46** [% CO_2eq]	van den Brink (2020)
C68	(a) Bituminous surface/(b) Recycled concrete slab	– **81**/– **82** [% CO_2eq]; – **77**/– **65** [% EP]	Küpfer et al. (2022)
C69	Recycled-concrete monolithic arch*	– **63** [% CO_2eq]; – **48** [% EP]	Küpfer et al. (2022)
C74	New concrete girders	– **44** [% CO_2eq]; – **49** [% $€_2$]	Vergoossen et al. (2021)
C75	Conventional cast-in-place structure (vs "Reuse 1")*	– **71%** [% CO_2eq]	Widmer (2022)

* Comparison with other alternatives is additionally available in the same source.

(Küpfer et al., 2023)

State-of-the-art: Reutilize to Decarbonize





- Reutilize and alternatives

a. Pavement reutilized-concrete block
b. Pavement with recycled-concrete block
c. Pavement with bituminous surfacing

Left to Right: ($1m^2$/ year)
1. Reutilized concrete brick wall
2. Clay brick façade
3. Light concrete brick wall

- Various decarbonization effect

(Küpfer et al., 2022; Vankunsten Architects et al., 2016)

State-of-the-art: Reutilize to Decarbonize

- Reutilize and alternatives

  a. Reused-concrete block pavement
  b. Pavement with recycled-concrete slab
  c. Pavement with bituminous surfacing

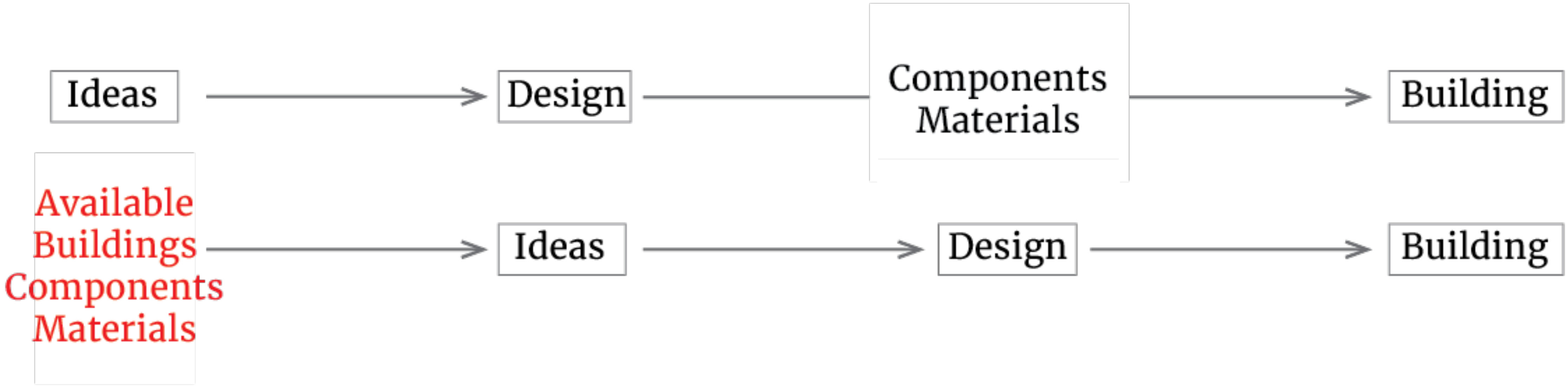
  Left to Right: ($1m^2$/ year)
  1. Used Concrete Brick Wall
  2. Clay Brick Façade
  3. Light Concrete Brick Wall

- Various decarbonization effect

(Küpfer et al., 2022; Vankunsten Architects et al., 2016)

The link between circular means and decarbonization is not well established.

Reuse: Material-driven Circular Design



(Gorgolewski et al., 2019)

Reuse: Material-driven Circular Design

Construction

- Pre-demolition audit
- Re-extraction (demolition)
- Transportation
- Storage
- Re-production (repair and remanufacture
- Re-installation
- Re-use stage
- End-of-life

Design

Supply Project

Demand Project

Assessment

- Value loss
- Environmental impacts
- Design aesthetics
- Time
- Cost
- Performance

(Gorgolewski et al., 2019; De Wolf et al.,2023)

Reuse Challenges

- Technical requirements (reverse engineering)
- Time sensitive
- Requires flexibility
- Complex evaluation
- Material Information

(Gorgolewski et al., 2019; De Wolf et al.,2023)

The lack of information of pre-existing material stocks to inform further reuse design, construction, and assessment.

information

material

Artificial Intelligence (AI)

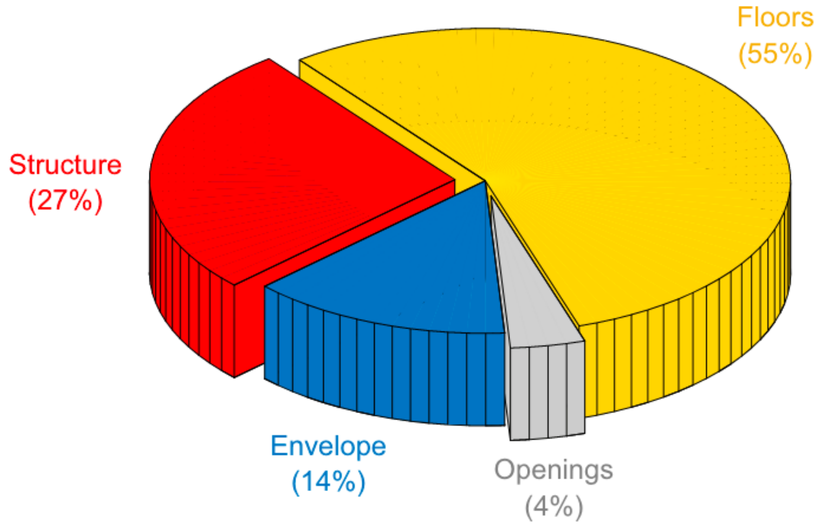
(inter Armeni et al., 2024)

State-of-the-Art: AI-supported EC Assessment

- Training
  - Processed data
    - Electricity production mix
    - Emission factor
  - Labels
    - Material name
- Validation
  - Error rate 7.5% - 20%
- Prediction
  - Building Structure
  - Building Envelope
  - Openings
  - Floors

Element	Construction Material	Embodied Carbon per Mass (kg-CO_{2e}/kg)	Volume (m^3)	Material Density (kg/m^3)	Embodied Carbon (kg-CO_{2e})
Building Structure					
Footings	Concrete	0.18	5.10	2,400	2,203.2
	Steel Bars	2.51	0.16	7,850	3,152.6
Connecting Beams	Concrete	0.18	1.54	2,400	665.28
	Steel Bars	2.51	0.05	7,850	985.2
Columns	Concrete	0.18	5.26	2,400	2,272.3
	Steel Bars	2.51	0.08	7,850	1,576.3
Beams	Concrete	0.18	7.96	2,400	3,438.7
	Steel Bars	2.51	0.16	7,850	3,152.6
Stairs	Concrete	0.18	1.58	2,400	682.6
	Steel Bars	2.51	0.03	7,850	591.1

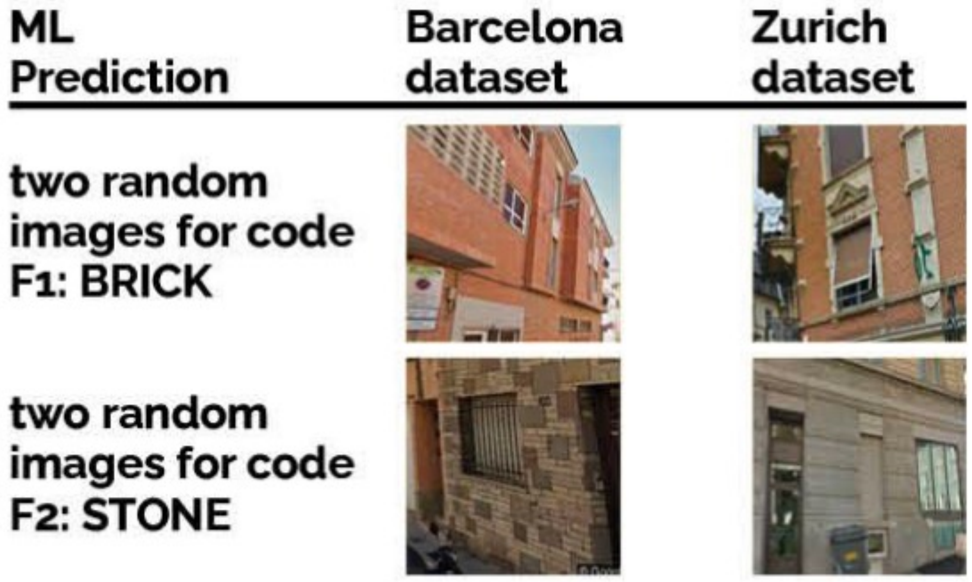
(...)



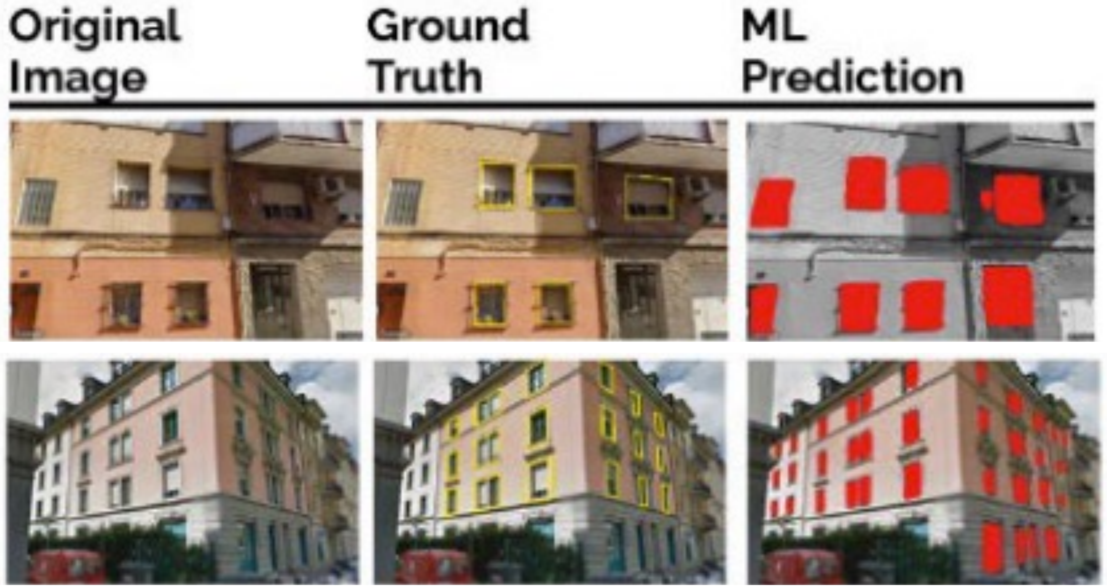
(Hafdaoui et al. 2023)

State-of-the-Art: AI and Pre-construction Audit

- Façade materials



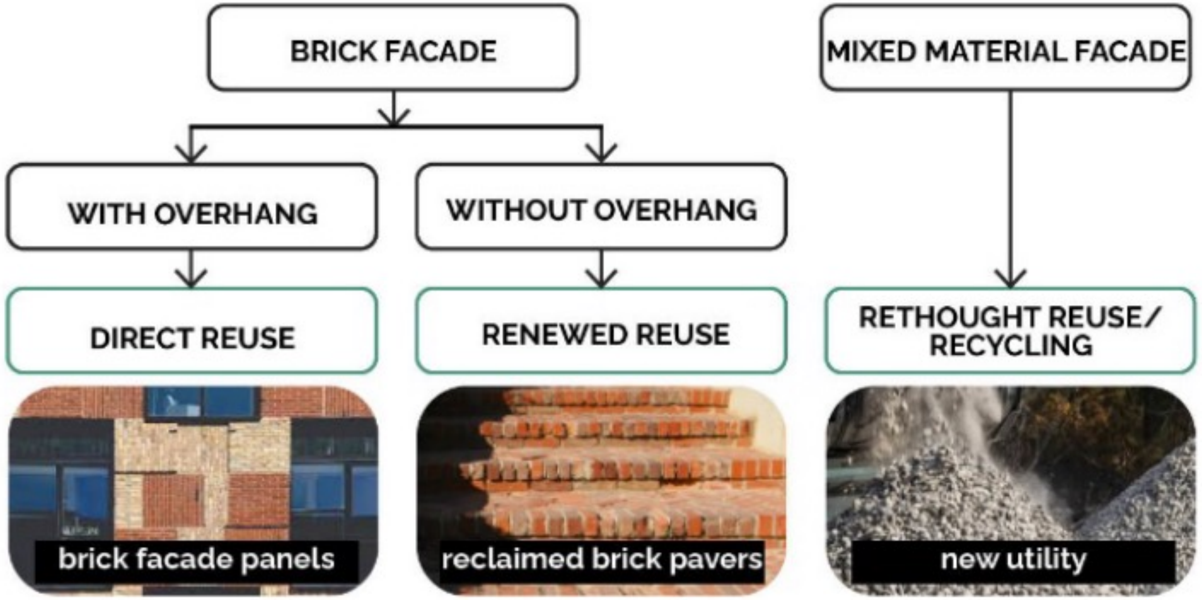
- Façade elements



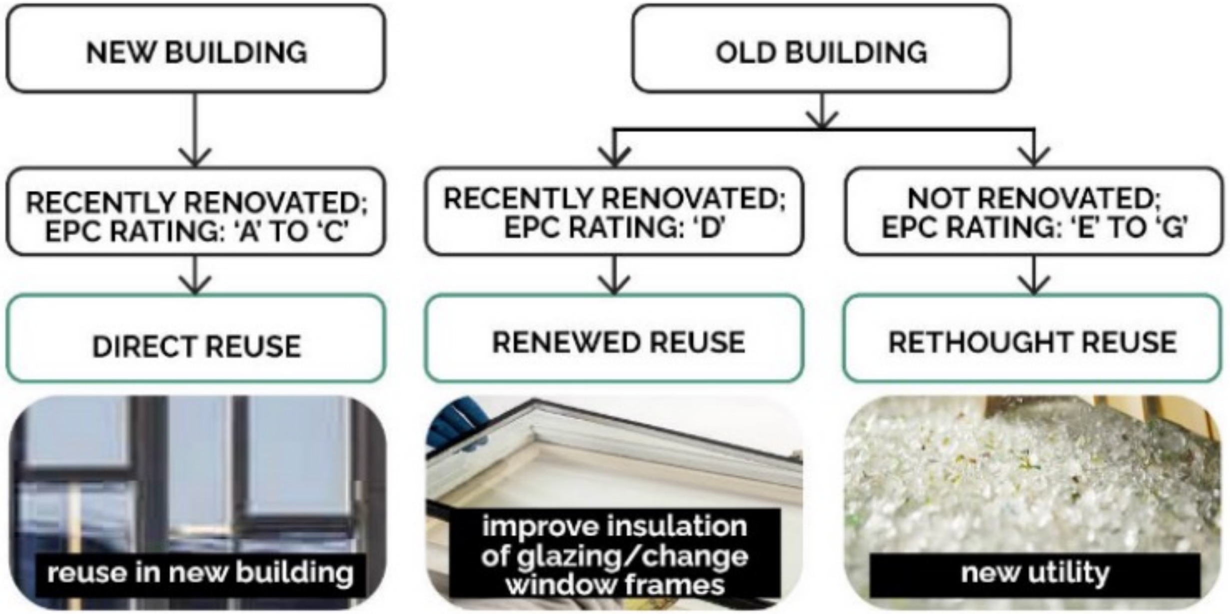
(Raghu et al., 2022)

State-of-the-Art: AI-supported Reuse Design

- Façade materials



- Façade elements



(Raghu et al., 2022)

The lack of feedback systems between supply (donor) and demand (receiver) projects.

State-of-the-Art: AI and Pre-construction Audit

- Data Collection
- Data processing
  - Material Classification
  - 3D Mesh Reconstruction
- Combined Information

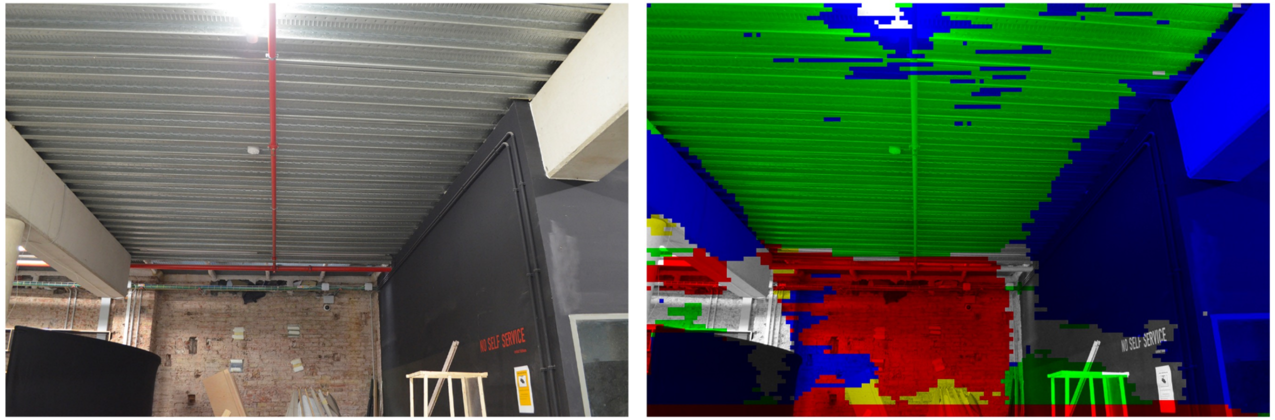


Figure 2. Material Localization.

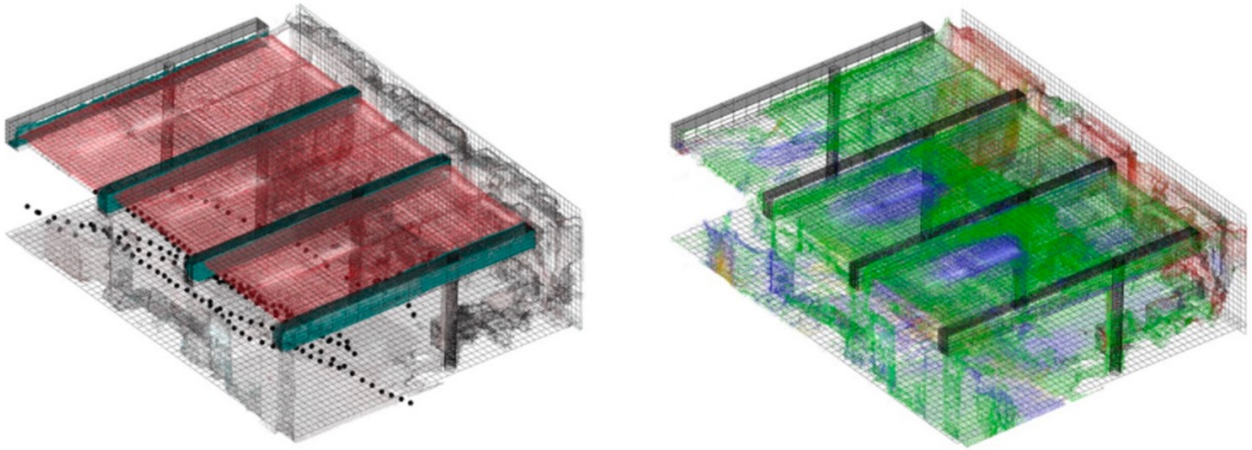
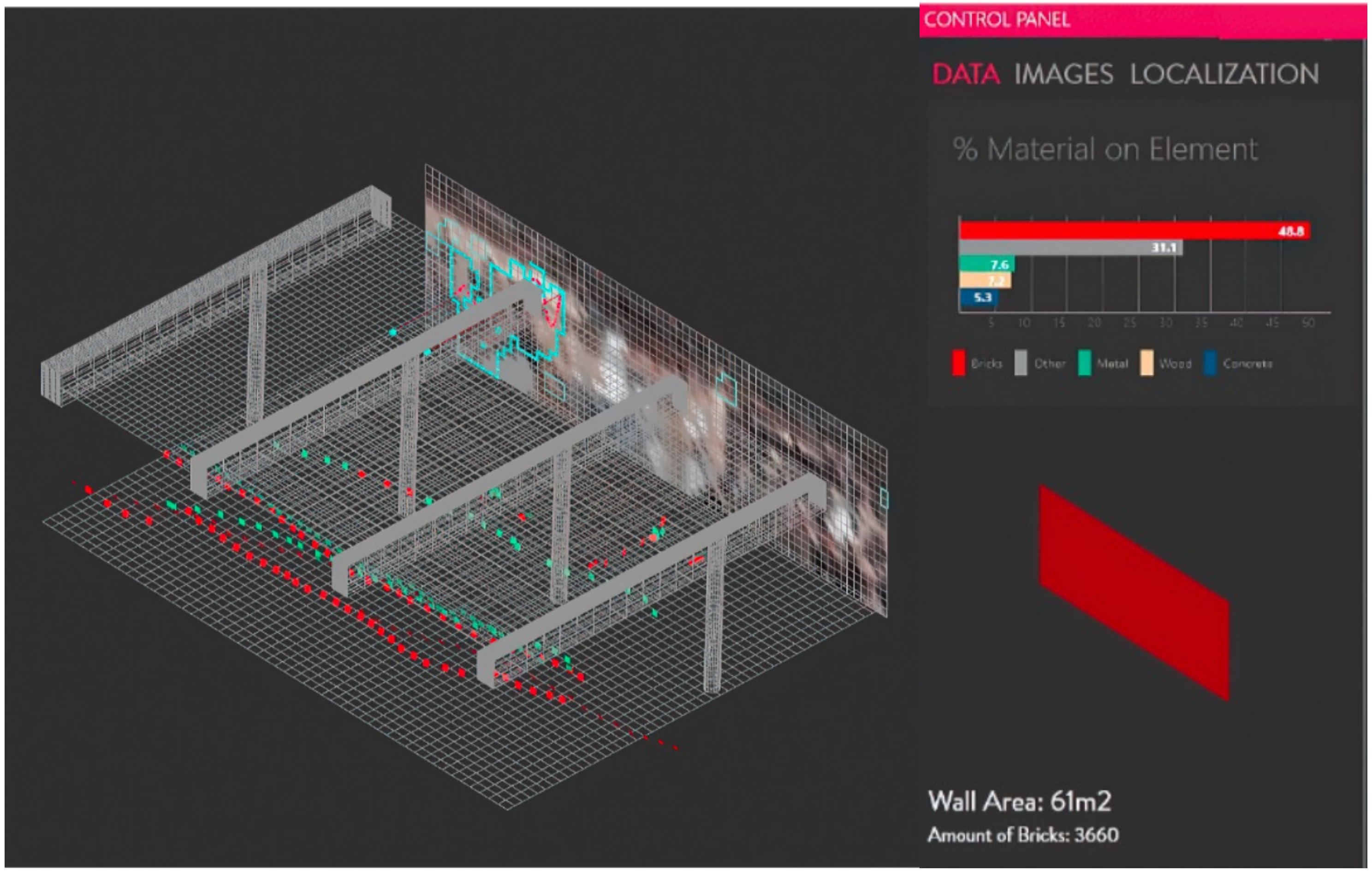


Figure 3. The isometric drawing on the left shows the original point cloud, camera locations

(Garcia et al. 2021)

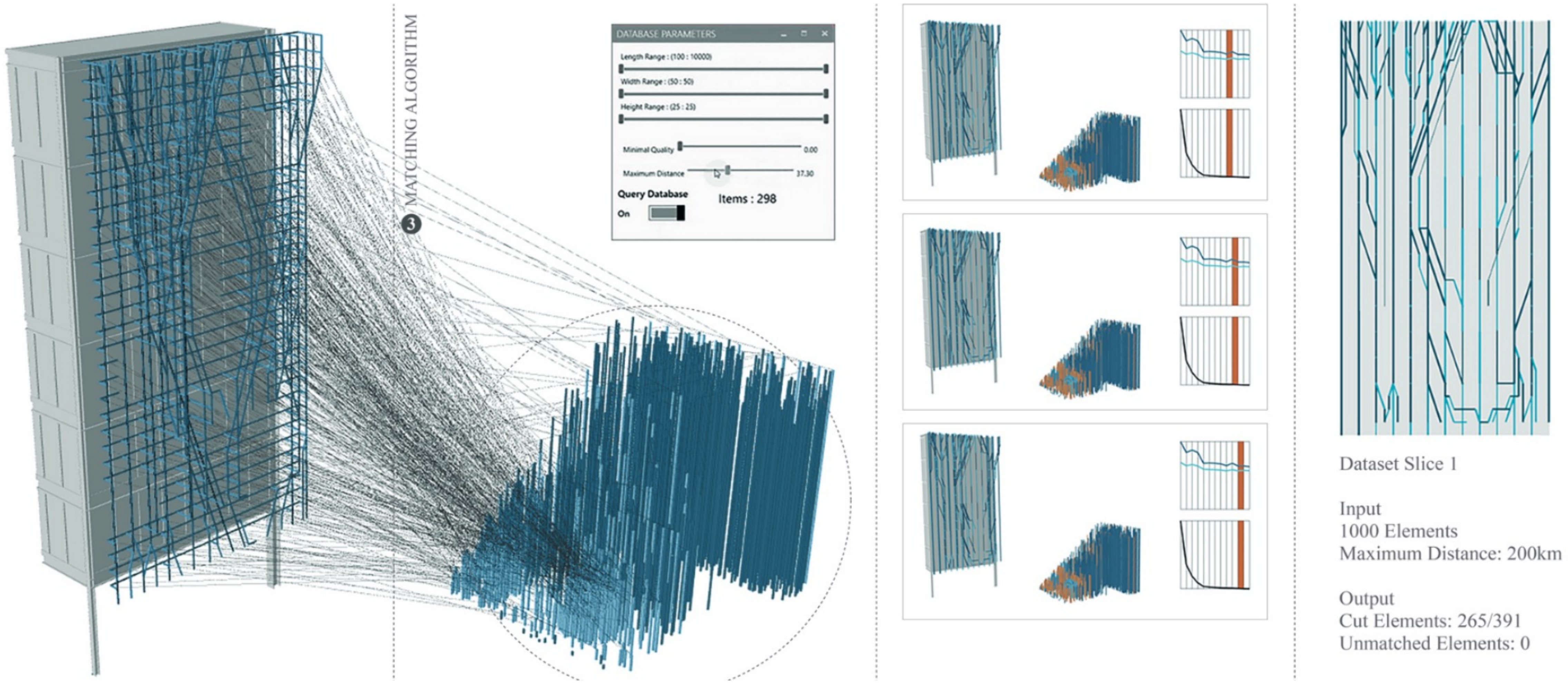
State-of-the-Art: AI and Pre-construction Audit

- Interface of EoL buildings
  - Demolition
  - Supply projects



(Garcia et al. 2021)

State-of-the-Art: AI-supported Reuse Design



Design input

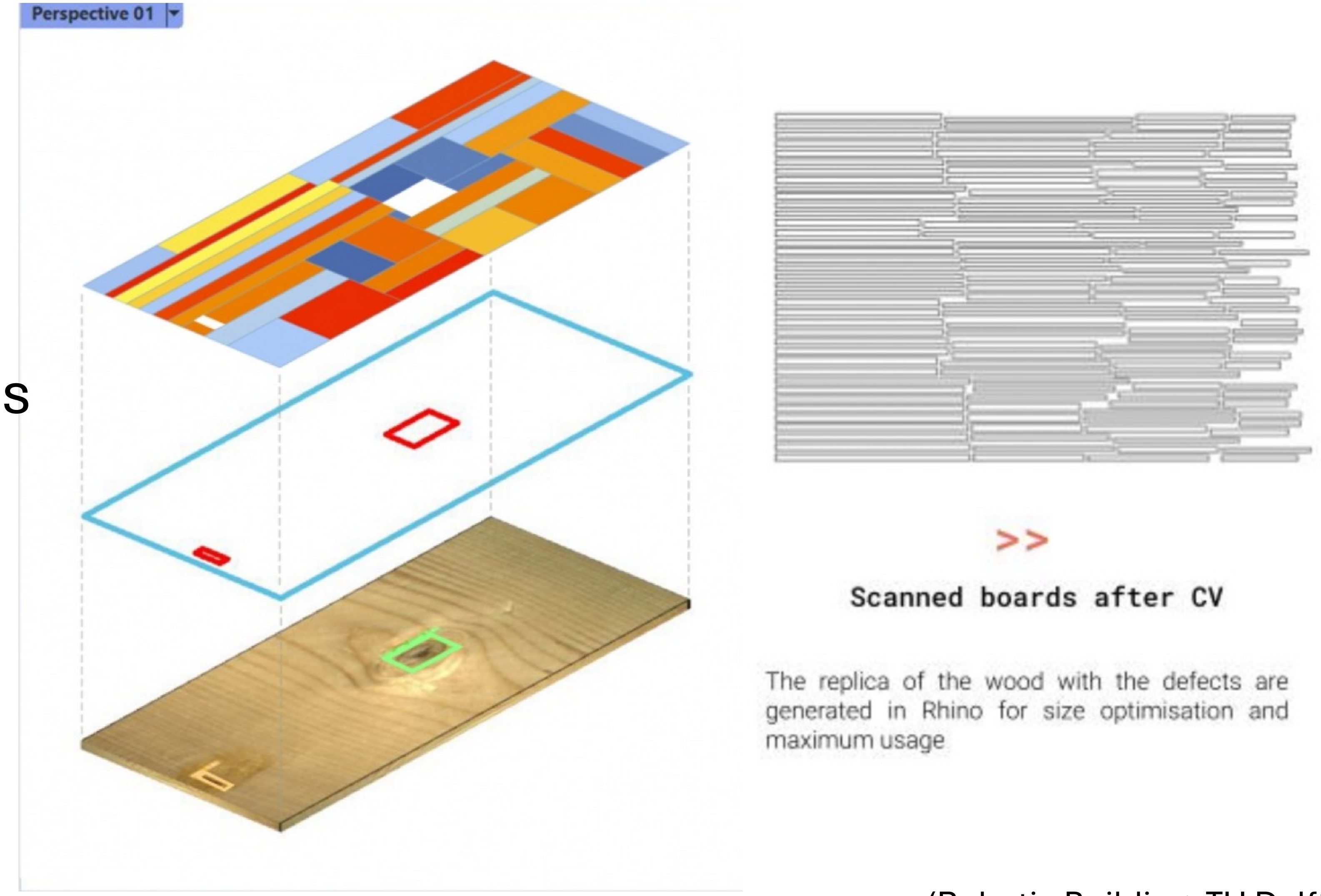
Stored material information

Scenarios

(Garcia et al. 2021)

State-of-the-Art: AI-supported Construction

- Defect recognition
- Bounding box
- Optimal Cut Pattern
- Fabrication Elements



(Robotic Building, TU Delft)

The lack of digital interfaces for information to be shared and utilized in reuse practice.

Research Gap

- Comparative assessment of reuse and decarbonization should be studied
- Decision-making model should be placed.
- (Digital) interfaces should be incorporated as design tools.

How to support a low CO_2 material-driven circular design through AI?

Research Question and Methodology

- **RQ1. What is the link between reuse and decarbonization?**
  - RQ1.1 Type: (a) retain, (b) reutilize, and (c) reprocess
  - RQ1.2 Scale: (i) downcycling, (ii) equivalent reuse, and (iii) upcycling
  - RQ1.3 Various materials
- Case studies

Research Question and Methodology

- **RQ2. How to incorporate information of pre-existing material stocks into design process ?**
  - RQ2.1 Where and what are the available stocks for circular means?
  - RQ2.2 How to re-/make the pre-existing stocks available for new design requirements?
- AI model development and testing in relevant cases.

Research Question and Methodology

- **RQ3. How to implement the material information to assist reuse assessment and decision-making?**
  - RQ3.1 Information (Material data)
  - RQ3.2 Interface (Platform, tool, network)
- The output (data) of RQ2 would be implemented to develop relevant digital interfaces.

Case Study

A

B

(Parabase, 2022; Anton et al., 2019)

Next Steps and Planning

- Circular concrete case studies (UPADSD Conference October)
- Extend circular material studies to others.
- Review of component reuse, retaining, reutilizing, and reprocessing
- Data collection: CO_2 / LCA dataset
- Review of AI and reuse design, construction, and assessment
- Go/no-go report (mid September)

(Potential) Research Output

(O1.1) Review of Circular Concrete Construction: CO2 Impact and Practice Concerns

(O1.2) Review of Recycled Materials Relevant for In-situ 3D Printing of Pop-up Habitats (co-author)

(O2.1) CV-supported approach for material classification and relocation.

(O2.2) CV-supported matching donor products and (new) design scenarios.

(O2.3) Review of component reuse: retain, reutilize, and reprocess, material property and design quality.

(O2.4) Publication of results.

(O3.1) Machine learning for CO_2 imprints on circular products.

(O3.2) AI-supported decision-making model / tool / platform.

(O3.3) Publication of results.

Courses

- ABE 009 Research Proposal (GS 4)
- ABE 013 Qualitative Research Methods (GS 4)
- ABE 023 Research Data Management (GS 1)
- PhD Start-up Module A-I
- PhD Start-up Module A-II
- PhD Start-up Module A-III
- Scientific Text Processing with LaTeX (GS 1.5)
- Geospatial Data Carpentry for Urbanism (GS 1.5)
- Elementary Dutch 1 (GS 3)
- AR0202 Computational Intelligence for Integrated Design (sit in)
- GEO5017 Machine Learning for the Built Environment (sit in)
- GEO Photogrammetry and 3D Computer Vision (Starting Q4)

Chapters Thesis

1. Introduction
    1.1 State-of-the-art
    1.4 Problem definition, research gap and questions
    1.5 Objectives, and methodology
    1.6 Contribution
2. Reuse in construction
    2.1 Circular building life cycles
    2.2 Types of reuse
    (...)
3. Reuse design workflow, supply, and demand
    3.1 Reuse paradigm
    3.2 Supply of buildings, components, and materials
    3.3 Demand design requirements
    3.4 AI-supported material data and workflow
    (...)
4. Reuse assessment
    4.1 Assessment and decision-making
    4.2 From material data to design information
    4.3 AI-supported digital design tools and methods
    (...)
5. Conclusion
6. References
7. Appendix

Data Management Plan

- DMP ID: 146869
- The data management plan is under development.
- Project Data (U: drive)
- 4TU.ResearchData

Thank you!